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Original Research Article

Effects of Vermicompost and Nitrogen Fertilizer on Selected Soil Properties in Tiyo District, Arsi Zone, Ethiopia

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Abstract: In Ethiopia, depletion of soil fertility is a significant barrier to sustainable agricultural production, especially in the highland regions where land use is intense. The focus of this study was to investigate how vermicompost (VC) and nitrogen (N) fertilization, alone and in conjunction with one another, affect the physical and chemical characteristics of soil and wheat (Triticum aestivum L.) yield at Kulumsa Agricultural Research Centre during the 2022 main growing season. This investigation consisted of 4 levels each of VC (0, 2.5, 5 and 7.5 t ha^{-1}) and N (0, 50, 100 and 150 kg N ha^{-1}) created through a two-way factorial arrangement within a randomized complete block design with three replications. Soil samples were taken prior to planting and after harvest so that the physical and chemical characteristics of soil could be tested, while the yield of wheat grain was measured once harvested. The findings from this research determine that applying vermicompost to soil can enhance its physical characteristics (such as decreasing bulk density while increasing total porosity and available water holding capacity) as well as improve its chemical properties (such as increasing organic carbon content; increasing plant available phosphorus levels; increasing exchangeable bases in the soil; and increasing cation exchange capacity). The combined effects of applying vermicompost and nitrogen fertilizer interacted positively to affect soil pH, total nitrogen content in addition to increasing the crop yield of wheat. The highest yield of wheat was achieved with the addition of 5 tha^{-1} vermicompost and 100 kg N/ha (i.e., 6.66 tha^{-1}) resulting in the greatest net economic return and acceptable marginal returns. Therefore, the integrated application of 5 t ha^{-1} vermicompost and 100 kg N ha^{-1} is recommended to improve soil fertility and wheat productivity in the study area and similar agro-ecological conditions.

Keywords: *soil fertility, nitrogen, wheat, grain yield*

1. INTRODUCTION

Soil fertility depletion caused by diminishing soil organic matter and nutrient losses continues to be a significant limitation to agricultural productivity in the tropics, particularly in the acidic highlands of Ethiopia (Lal, 2020; FAO, 2021). Continuous cropping without adequate nutrient replenishment, alongside erosion and leaching, contributed to rapid soil degradation in intensively farmed regions, resulting in diminished productivity of key cereal crops, including wheat, barley, maize, and teff (Karltun et al., 2013; Belachew et al., 2022). Poor soil management and the strong links between soil properties, landscape position, and farming systems make nutrient loss and yield loss more severe (Woldeamlak, 2003; Taye & Yifru, 2010).

Ethiopia's crop production depends significantly on synthetic fertilizers. Mineral fertilizers are important for getting more crops, but using them too much and too often, especially nitrogen fertilizers, has caused low nutrient use efficiency, nitrate leaching, greenhouse gas emissions, and a long-term decline in soil quality (Pingali & Barrow, 2012; Zaman et al., 2012; Sommer et al., 2015). At the same time, more people imply that less land is available, which makes fallowing impossible and makes people rely more on inorganic fertilizers (Bationo et al., 2007; Vanlauwe et al., 2021).

Integrated soil fertility management (ISFM), which uses both organic and inorganic nutrient sources, is a long-term way to make soil more fertile, use nutrients more efficiently, and grow more crops. Organic amendments improve the structure of the soil, the activity of microbes, and the ability of the soil to hold water, but they are unable to meet the nutrient needs of high-yielding varieties on their own because they release nutrients slowly (Li et al., 2018;. When used with mineral

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fertilizers, vermicompost has shown a lot of assure for improving soil quality and crop yields (Dwivedi et al., 2016; Shah & Wu, 2019).

Wheat (Triticum aestivum L.) is a major staple crop in Ethiopia, grown across a broad altitudinal range, with ideal production occurring between 1900 and 2700 meters above sea level (Hailu, 1991). Even though yields have risen in the last few decades, productivity remains below potential because soil fertility management is inadequate (CSA, 2018). Ethiopia imports inorganic fertilizers, yet it has abundant organic resources that are underused. Blanket fertilizer recommendations often overlook integrated nutrient management techniques.

Therefore, this study was conducted to evaluate the effects of the combined application of vermicompost and nitrogen fertilizer on selected soil physicochemical properties, wheat yield, and yield components in Tiyo district, southeastern Ethiopia. The specific objectives were to:

- To assess the effects of vermicompost and nitrogen fertilizer on selected soil physicochemical properties
- To determine the effects of vermicompost and nitrogen fertilizer on yield and yield components of wheat at Kulumsa Agricultural Research Center
- To identify the most economically viable combination of vermicompost and nitrogen fertilizer rates for wheat production

2. MATERIALS AND METHODS

2.1. Description of the Study Area

2.1.1. Geographical location

The experiment was conducted at Kulumsa Agricultural Research Center (KARC), which is located in Tiyo District, Arsi Zone, Oromia Regional State, and situated at an altitude of 2200 meter above sea level. The experimental site is 8 km North of Assela, Zonal capital town, and 167 km Southeast of Addis Ababa. Its geographical extent is from 8º01' 10" to 8º 02' 23" N latitude and from 39º 07' 27" to 39º 09' 11" E longitude (Figure 1).

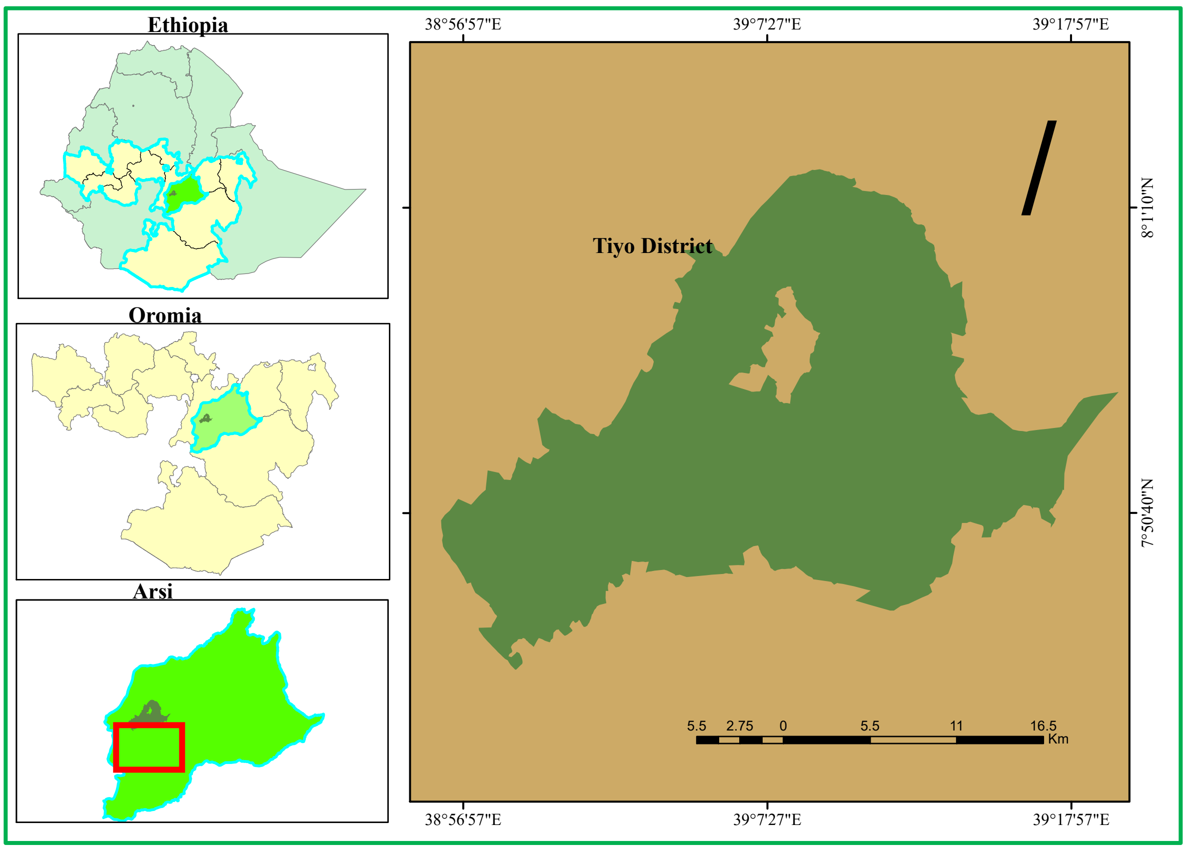

Figure 1. Location map of the study area.

2.1.2. Climate, topography and soil type

The study area is characterized bimodal rainfall distribution. The data obtained from the weather station located at KARC reveal that the area receives a mean annual precipitation of 844 mm. The rainfall distribution is high during the two summer months (July and August), whereas the mean minimum and maximum temperatures were 9.9°C and 23.08°C, respectively, in 2015-2021.

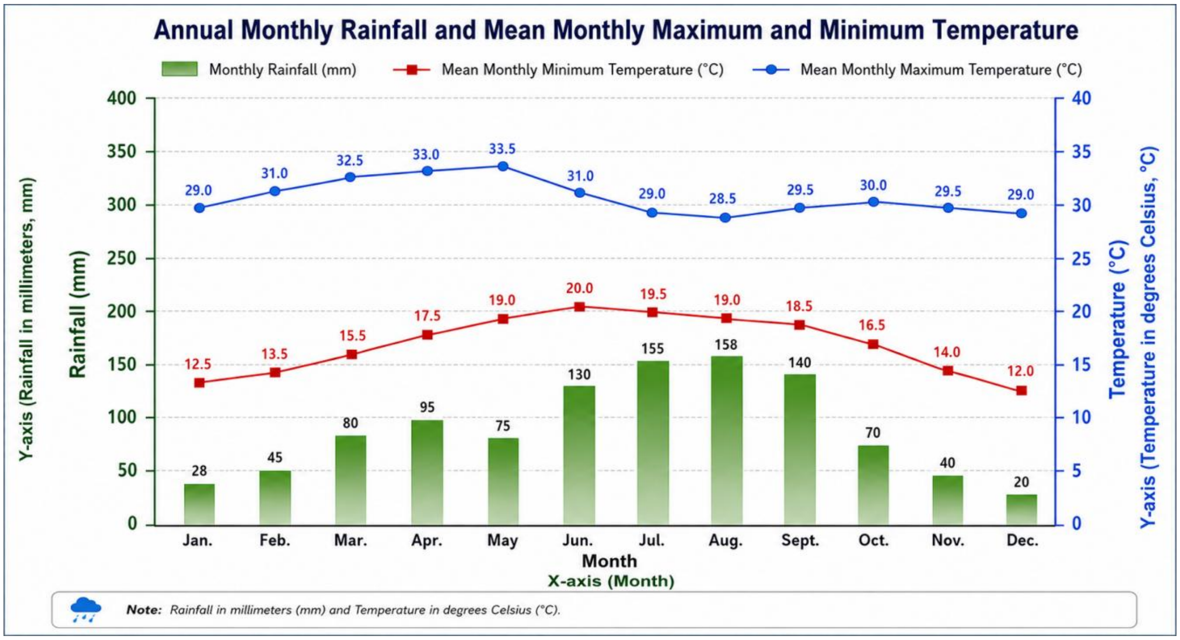

Figure 2. Annual monthly rainfall, mean monthly maximum and minimum temperature of study area

Its topography is moderately elevated and gentle sloping. The soil type at KARC is predominantly Vertic Luvisol, characterized by well-drained soils with a dark clay loam texture. (Esayas et al., 2003).

2.1.3. Population, land uses and farming system

Tiyo District has a total population of 125,714, including 62,538 males and 63,176 females (Ethiopian Statistics Service, 2022). Most people live in rural areas. The district spans 665 km², which is about 3.09% of the zone. The land use breakdown shows that 41.57% is cultivated land, 13.73% is pasture land, 4.23% is forest land, 14.98% is bush and shrub land, 9.51% is for construction, and 15.98% includes other land types, such as mountainous regions (AZARDO, 2008/09). Among the cultivated land, cereals make up 82.86%, pulses account for 15.29%, and oil crops represent 1.85%. The main crops in the district, listed by area, are wheat (11,805 ha), barley (6,311 ha), faba bean (1,677.5 ha), teff (1,502.9 ha), field pea (1,330 ha), linseed (244.4 ha), and rapeseed (193 ha) (AZARDO, 2018/19**).**

Tiyo District is considered a high-potential area for both crop and livestock farming. The dominant farming system is mixed agriculture, which integrates crop cultivation with livestock raising, typical of southeastern Ethiopia. The primary crops include wheat, teff, barley, maize, and potatoes. Livestock farming is also significant, with cattle, sheep, and goats the most commonly raised animals. Traditional oxen power is the main source of traction for plowing, while harvesting and threshing are mostly done with combine harvesters.

2.2. Experimental Materials and Design

2.2.1. Experimental materials

Bread wheat variety called "*Ogolcho*" was used as an experimental crop. The variety was released by Kulumsa Agricultural Research Center in 2012 cropping season. It has a maturity period of 105 days and a yield potential of 3.3-5.0 t ha^{-1} (MoA, 2012). It was selected for its adaptation, better performance, and disease resistance in the study area. Urea (46% N) and triple super phosphate (TSP, 46% P_2O_5) were used as inorganic fertilizer sources, while vermicompost was used as organic fertilizer source.

2.2.2. Experimental design

The experiment was conducted using a randomized complete block design (RCBD) with three replications and sixteen treatment combinations. Treatments combined four levels of vermicompost (0, 2.5, 5, and 7.5 t ha^{-1}) with four rates of nitrogen (0, 23, 46, and 69 kg N ha^{-1}) applied as urea (46% N). All plots received a uniform rate of phosphorus at planting, 69 kg P_2O_5 ha^{-1} as triple superphosphate (TSP, 46% P_2O_5), following the guidelines of Legesse and Saketu (2017). The total area for the experiment was 41.5 m × 13 m (539 m²). Plots were spaced 0.5 m apart, and blocks were separated by 1 m. Each plot was 6 m² and contained ten rows spaced 20 cm apart.

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2.2.3. Experimental procedures and field management

The experimental field was ploughed four times using both tractor and oxen to achieve a fine tilth, and the plots were subsequently leveled manually. The field layout was prepared, and treatments were randomly assigned to experimental units within each block. Bread wheat was sown in May 2021 at the recommended seed rate of 150 kg ha^{-1}. Sowing was carried out manually by drilling in rows spaced 20 cm apart. Vermicompost was applied uniformly to the designated plots two weeks before planting, incorporated into the topsoil layer to ensure proper mixing (Negessa *et al.,* 2021). Nitrogen fertilizer (urea, 46% N) was applied in two equal splits to improve nitrogen use efficiency and minimize losses: half at planting and the remaining half at the mid-tillering stage during light rainfall. Phosphorus fertilizer was applied uniformly to all plots at a rate of 69 kg P_2O_5 ha^{-1} in the form of triple superphosphate (TSP) at sowing, banded along the rows in accordance with the recommendations of Legesse and Saketu (2017). All other agronomic practices, including weeding, harvesting, and threshing, were carried out manually.

2.2.4. Soil sampling and sample preparation

Soil samples were taken from the experimental field before planting and after harvest. Before planting, five subsamples of soil were collected from 0-20 cm depth in a zig-zag pattern across the experimental site using an auger. These samples were mixed thoroughly and about one kg of composite sample was prepared by quadrant method. In addition, five undisturbed samples (diameter of 5 cm and height of 5cm) were randomly collected from the experimental site at the depth of 0-20cm by using core sampler to determine the soil bulk density and the available water holding capacity. Similarly, soil samples from each experimental plot were collected at same depth after harvest of the crop. Undisturbed soil samples (0-20cm) from the center of each plot were also taken to determine soil bulk density and water holding capacity. Finally total soil samples were properly packed and labeled in polythene plastic bags and submitted to Kulumsa Soil Laboratory Center. Composite soil samples were air dried and ground to pass through 2 mm sieve to determine selected properties of soil except for organic carbon and total nitrogen in which case 0.5 mm sieve was used. Then, the selected physicochemical properties were determined in the soil samples according to the standard laboratory procedures.

2.3. Soil laboratory analysis

The Bouyoucos hydrometer method is used to determine the distribution of soil particle sizes (Day, 1965). Soil texture classes were determined based on sand, silt, and clay using the USDA textural triangle (Soil Survey Staff, 1999). The bulk density of the soil was determined using the core method (Jamison et al., 1950), and a particle density of 2.65 g cm^{-3} was assumed when calculating the total soil porosity (Rowell, 1994). Soil water retention at field capacity (FC; -0.33 bar) was obtained from undisturbed soil core samples, while the permanent wilting point (PWP; -15 bars) was ascertained from disturbed soil core samples by the pressure plate extraction method. Available water holding capacity (AWC) was determined as the difference between the FC and PWP values (Hillel, 1980) and expressed as a mass per volume.

Soil pH was measured by preparing a 1:2.5 (w/v) soil-to-water suspension and measuring pH with a glass electrode pH meter (McLean 1982). Soil organic carbon content was measured using the Walkley and Black Wet Oxidation Method (Walkley and Black 1934), and total nitrogen content was measured using the Kjeldahl digestion method (Bremner and Mulvaney 1982). Available phosphorus in the soil was extracted using the Bray II method (Bray and Kurtz 1945) and quantified with a spectrophotometer following Murphy and Riley (1962). Determinations of cation exchange capacity (CEC) and each of the exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, and Na^+) were accomplished through extractions with 1 N ammonium acetate (NH_4OAc) at pH 7. Base saturations were calibrated by measuring exchangeable Ca^{2+} and Mg^{2+} with an atomic absorption spectrophotometer and K^+ and Na^+ with a flame photometer (Rowell 1994). Percent base saturation (PBS) was calculated using the formula for cumulative exchangeable bases divided by the soil's cation exchange capacity, expressed as:

$$PBS(\%)=Exchangeable\frac{[Ca+Mg+K+Na]_{x100}}{CEC}\ldots\ldots\ldots$$

Since, all parameters were the same unit which was, cmol (+) Kg^{-1}) of soil.

2.4. Vermicompost Preparation and Analysis.

Vermicompost was prepared by using locally available organic materials like animal dung, pulse residues (chickpea, haricot bean and faba bean) and crop residues such as straw and leaves. The materials were pre-composted under aerobic conditions for 2–3 weeks to reduce heat and improve suitability for earthworms. The partially decomposed materials were then placed in a vermicomposting bed prepared in a shaded and well drained area, with straw as a base layer for aeration. The moisture level was maintained at 60-70% and Earthworms (Eisenia fetida) were introduced. Decomposition was carried out under aerobic conditions for 45–60 days. The vermicompost was considered mature when it turned dark, granular and odorless. Finally it was harvested, air dried in shade and sieved to be used in the experiment.

To assess the pH value of the vermicompost, we measured the pH from a saturated extract of the vermicompost using a glass electrode pH meter according to McLean (1982). The total organic carbon (TOC) was determined using the method described by

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Nelson and Sommers (1982). Total nitrogen was determined by conducting the Kjeldahl digestion procedure (Bremner and Mulvaney, 1982). Total available phosphorus (P) was determined using the colorimetric method, while the concentration of total phosphorus was determined using the method of Murphy and Riley (1962). The amounts of total potassium (K), sodium (Na), and calcium (Ca) were analysed through flame photometry (Bansal and Kapoor, 2000).

2.5. Data Analysis

All soil and agronomic data were analyzed using analysis of variance (ANOVA) with the GLM procedure of SAS version 9.0 (SAS Institute, 2008). When treatment effects were significant, mean separation was done using Duncan's Multiple Range Test (DMRT) at a 5% significance level.

2.6. Economic Analysis

Economic analysis was done to determine the feasibility of treatments using partial budget analysis, dominance analysis and marginal rate of return (MRR) following CIMMYT (1988). To simulate farmer's conditions, mean grain yields were reduced by 10 % to account for the differences between experimental and on-farm yields.

The gross benefit is derived by computing the price of wheat (40.0 ETB kg⁻¹) along with the matured/processed straw (2.5 ETB kg⁻¹) multiplied by the associated Adjusted Grain Yield, per Tolera & Matthews (2006). The total variable costs are mineral fertilizer and labour costs associated with harvesting, collecting, transporting, and applying the pesticide made from vermicompost. The following are the costs: Vermicompost (4 ETB kg^{-1}), Urea Fertilizer (37.5 ETB kg^{-1}), the labour to apply fertilizer (50 ETB $person^{-1}$ day^{-1}), transport and application of vermicompost (50 ETB per person), and harvesting and post-harvest costs which vary with the amount of yield produced. The net benefit (NB) is the difference between the gross benefit and the total variable costs (TVC). The marginal rate of return (MRR), which measures the economic advantage of one treatment to another, can be computed using:

$$MRR(\%)=\frac{\Delta TVC}{\Delta NB} * 100 \ldots$$

where ΔNB is the change in net benefit and ΔTVC is the change in total variable cost between successive treatments. Treatments were considered economically acceptable when the MRR exceeded 100%, as recommended by CIMMYT (1988). Fixed costs common to all treatments were excluded from the analysis.

3. Results and Discussion

3.1 Selected Physicochemical Properties of Soils of the Experimental Sites

Laboratory analysis of the surface soil showed that it contained 54.38% sand, 31.25% clay, and 14.38% silt, and was classified as sandy clay loam based on the USDA soil textural triangle (Soil Survey Staff, 1999). This textural class is generally favorable for cereal production due to its balanced drainage and moisture retention characteristics. The measured bulk density of 1.27 g cm^{-3} indicated a well-structured soil that allows adequate root penetration, aeration, and water movement. Similarly, the total porosity (52.26%) exceeded the critical threshold required for optimum root development and soil aeration (Brady and Weil, 2008).

The soil exhibited an available water holding capacity (AWHC) of 147.6 mm m^{-1}, calculated as the difference between field capacity (215.7 mm m^{-1}) and the permanent wilting point (68.1 mm m^{-1}). Beernaert (1990) classifies this value as in the medium water retention class. This suggests the soil can hold enough moisture for crop growth, but adding organic matter could further improve its water-holding capacity.

Table 1. Physical and chemical properties of the soil at the experimental site

Property	Value
Physical properties	
Textural class	Sandy clay loam
Sand (%)	54.38
Silt (%)	14.38
Clay (%)	31.25
Bulk density (g cm^{-3})	1.27
Total porosity (%)	52.26
Field capacity (mm m^{-1})	215.7
Permanent wilting point (mm m^{-1})	68.1

AWHC (mm m^{-1})	147.6
Chemical properties	
pH (H_2O)	6.23
Organic carbon (%)	1.92
Total N (%)	0.14
Available P (mg kg^{-1})	8.3
Exchangeable K (cmol(+) kg^{-1})	2.86
Exchangeable Ca (cmol(+) kg^{-1})	9.41
Exchangeable Mg (cmol(+) kg^{-1})	2.93
Exchangeable Na (cmol(+) kg^{-1})	0.66
CEC (cmol(+) kg^{-1})	18.67
Base saturation (%)	69.96

The soil analysis showed a slightly acidic pH of 6.23, relatively at the optimal point for wheat growth and good nutrient uptake. Organic carbon came in at 1.92%, which just barely keeps the soil's structure and its biological activity in good condition. But total nitrogen at 0.14% and available phosphorus at 8.3 mg/kg are both low, pointing to some nutrient limitations that could hold back crop yields.

Exchangeable potassium was rather high at 2.86 cmol(+) kg^{-1}. Calcium and magnesium—9.41 and 2.93 cmol(+) kg^{-1}—were both at solid, healthy levels for plants. Sodium stood out a bit; at 0.66 cmol(+) kg^{-1}, it was slightly above the ideal but wasn't high enough to bring about any immediate concerns. The soil's cation exchange capacity hit 18.67 cmol(+) kg^{-1}, and base saturation reached 69.96%. So, the soil has retained most of its nutrients and is able to retain nutrients effectively—good news for those considering planting cereal crops (as long as you manage nutrients properly).

3.2. Chemical composition of vermicompost

The pH level of vermicompost is moderately alkaline at 7.67 (Table 3). In addition to this, according to the test results, the mean levels of organic carbon and total nitrogen of vermicompost were found to be 9.17% and 1.66%, respectively (Table 3). Likewise, the phosphorus concentration of vermicompost was determined to be 21.49 ppm. The average levels of the exchangeable bases in vermicompost, including potassium, calcium, magnesium, and sodium were 19.73, 25.25, 7.81, and 1.46 cmol (+) kg-1, respectively. The cation exchange capacity (CEC) of vermicompost is 36.02 cmol (+) kg^{-1}.

Table 2. Chemical composition of vermicompost

Chemical properties	Result
pH	7.67
carbon (%)	9.17
Total nitrogen (%)	1.66
Phosphorous (mg/kg)	21.49
Potassium ($Cmol_{(+)}kg^{-1}$)	19.73
Calcium ($Cmol_{(+)}kg^{-1}$)	25.25
Magnesium ($Cmol_{(+)}kg^{-1}$)	7.81
Sodium ($Cmol_{(+)}kg^{-1}$)	1.46
CEC ($Cmol_{(+)}kg^{-1}$)	36.02

3.3. Effect of vermicompost and urea on selected soil properties after harvesting

3.3.1. Soil physical properties

ANOVA results indicate that there is a significant ($p \leq 0.05$) effect of vermicompost on soil bulk density, total porosity, and Available Water Holding Capacity (Table 5). Higher doses of vermicompost lower soil bulk density and increase porosity and AWHC. The bulk density of the soil was observed to decrease with increasing amounts of vermicompost addition, with the least value of 1.11 g cm^{-3} being noted at 7.5 t ha^{-1}, resulting in a reduction of 11.9% in comparison to the control. These results indicate that there was a significant reduction in soil compaction and increase in pore space. Similar findings have been documented by Mulugeta and Getahun (2020) and Van et al. (2011) regarding the reduction of bulk density on the application of vermicompost. Total porosity and AWHC were found to be increased significantly due to vermicompost addition rates. The highest value for porosity and AWHC was noted at 7.5 t ha^{-1}.

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Table 3. Main effects of vermicompost on soil physical properties after harvest

Treatment	Bulk density (g cm⁻³)	Total porosity (%)	AWHC (mm m⁻¹)
Vermicompost(tha⁻¹)			
0	1.26a	52.45d	145.6d
2.5	1.21b	54.34c	156.7c
5.0	1.17c	55.85b	172.7b
7.5	1.11d	57.98a	192.3a
LSD (0.05)	0.02	0.74	2.23
CV (%)	0.80	0.65	0.65

Means followed by the same letter within a column are not significantly different at p ≥ 0.05 (DMRT).

3.3.2. Soil chemical properties

3.3.2.1 Soil pH and total nitrogen

Interaction between vermicompost and urea had a significant effect (P ≤ 0.05) on soil pH (Table 6), whereas the main effect of urea alone did not show any significance. The soil pH showed an increasing trend with the increase in vermicompost levels, where maximum soil pH (7.09) was obtained at 7.5 t ha⁻¹ vermicompost + 100 kg ha⁻¹ urea, which gave an increase of 15.5% compared to the control. This is due to the neutralizing effect of vermicompost with high soil organic carbon content, according to Gopinath et al. (2008) and Girma and Zeleke (2017).

Table 4. Interaction effects of vermicompost and urea on soil pH

VC (t ha⁻¹)	0	50	100	150
0	6.10hi	6.06i	6.15gh	6.15gh
2.5	6.47f	6.52ef	6.53ef	6.54e
5.0	6.72d	6.81c	6.79cd	6.83c
7.5	7.01b	7.00b	7.09a	7.04ab
$LSD_{0.05}$				0.077
CV%				61

Means followed by the same letter within a column are not significantly different at p ≥ 0.05 (DMRT).

The effect of the application of vermicompost and urea on the total nitrogen content of soils was significant (Table 7). The nitrogen content varied between 0.112% (control) and 0.311% with the combination of 7.5 t ha⁻¹ vermicompost and 150 kg ha⁻¹ urea, which represents an increment of 63.99% over the control.

Table 5. Interaction effects of vermicompost and urea on total soil nitrogen (%)

VC (t ha⁻¹)	0	50	100	150
0	0.112m	0.123l	0.126kl	0.135k
2.5	0.203j	0.208ij	0.216hi	0.222h
5.0	0.232g	0.238fg	0.245f	0.256e
7.5	0.268d	0.279c	0.296b	0.311a
$LSD_{0.05}$				0.01
CV%				2.36

Means followed by the same letter within a column are not significantly different at p ≥ 0.05 (DMRT).

3.3.2.2 Soil organic carbon and available phosphorus

Vermicompost had a highly significant effect on soil organic carbon (SOC) and available phosphorus (P), while urea and its interaction did not have a significant effect (Table 8). The SOC increased from 1.77% to 3.98% at 7.5 t ha⁻¹. It can be seen that there was a considerable improvement in soil fertility. Available P increased from 8.06 to 15.20 mg kg⁻¹, falling within the medium range according to Hazelton & Murphy (2016).

Table 6. Main effects of vermicompost on soil organic carbon and available phosphorus

Treatment	SOC (%)	Available P (mg kg⁻¹)
Vermicompost (t ha⁻¹)		
0	1.77d	8.06d
2.5	2.64c	10.21c

5.0	3.23b	12.46b
7.5	3.98a	15.20a
$LSD_{0.05}$	0.07	0.06
CV%	1.29	0.25

Means followed by the same letter within a column are not significantly different at p ≥ 0.05 (DMRT).

3.3.2.3 Exchangeable bases and cation exchange capacity

There was a highly significant effect ($p \leq 0.05$) of vermicompost on exchangeable calcium, magnesium, potassium, and CEC, while urea and their interaction had no significant effects (Table 9). The maximum values were observed in the application of 7.5 t ha⁻¹, with an increase in CEC by 20.6% compared to the control treatment. Such results can be attributed to the increased organic matter content and soil pH levels.

Table 7. Main effects of vermicompost on exchangeable bases and CEC

VC (t ha⁻¹)	K	Ca	Mg	Na	CEC
0	2.82d	9.44d	2.90d	0.66	21.61d
2.5	2.96c	10.26c	4.02c	0.67	23.91c
5.0	3.20b	11.40b	4.42b	0.67	25.02b
7.5	3.30a	12.56a	5.22a	0.66	26.28a
$LSD_{0.05}$	0.036	0.049	0.18	NS	0.22
CV%	0.57	0.22	2.12	0.83	0.45

Means followed by the same letter within a column are not significantly different at p ≥ 0.05 (DMRT).

3.4. Effect of Vermicompost and Urea(N) on Wheat Yield

3.4.1 Grain Yield

The effect of vermicompost (VC) and nitrogen had significant ($P \leq 0.05$) impacts on the grain yield of wheat (Table 16). The highest grain yield (6.66 t ha⁻¹) was realized when 5 t VC ha⁻¹ and 100 kg urea ha⁻¹ were applied together, whereas the lowest grain yield (1.84 t ha⁻¹) was obtained from the control. Thus, the integration of organic and inorganic fertilizer applications resulted in better yields as compared to their individual applications.

The increase in grain yield was 72.37% greater in the integrated treatment than the control, which showed a highly responsive grain yield of wheat. This finding agrees with earlier research results by Molla et al. (2017), Hulumtaye et al. (2021), Zaman et al. (2018), and Wassie (2018) regarding the beneficial impact of combined organic and inorganic fertilizer applications.

Table 8 . Interaction effect of vermicompost and N on grain yield(t/ha)

Vermicompost rate t/ha	Urea rate kg/ha			
	0	50	100	150
0	1.84^{i}	2.68^{h}	4.18^{g}	4.66^{ef}
2.5	2.57^{h}	3.98^{g}	5.00^{de}	5.14^{d}
5	4.10^{g}	4.90^{d-f}	6.66^{a}	6.14^{b}
7.5	4.56^{f}	5.62^{c}	6.32^{ab}	6.15^{b}
$LSD_{0.05}$			0.38	
CV%			2.65	

Means followed by the same letter within a column are not significantly different at p ≥ 0.05 (DMRT).

3.4.2 Straw Yield

The study revealed that the effect of urea on VC significantly ($P \leq 0.05$) influenced the wheat straw production (Table 15). The maximum straw production (11.09 t ha⁻¹) was obtained from the plot treated with 150 kg urea ha⁻¹ and 7.5 t VC ha⁻¹, which did not differ significantly from plots that received 7.5 t VC ha⁻¹ and 100 kg urea ha⁻¹ and 5 t VC ha⁻¹ and 100 and 150 kg urea ha⁻¹. The minimum straw yield (6.49 t ha⁻¹) was obtained from the untreated plot (control).

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The increment in straw production could be due to the combination of nutrient supply from both organic and inorganic sources, which promotes vegetative development. This result is in harmony with the findings reported by Molla et al. (2018), Mekonnen et al. (2020), and Kumar et al. (2017).

Table 9 . Interaction effect of vermicompost and N on straw yield(t/ha)

Vermicompost rate t/ha	Urea rate kg/ha			
	0	50	100	150
0	6.49^{j}	7.23^{i}	7.99^{h}	8.30^{f-h}
2.5	7.16^{i}	8.39^{e-g}	8.67^{de}	8.84^{cd}
5	8.25^{gh}	8.63^{d-f}	10.54^{b}	11.01^{a}
7.5	8.63^{d-f}	9.04^{c}	10.61^{b}	11.09^{a}
$LSD_{0.05}$			0.38	
CV%			2.30	

Means followed by the same letter within a column are not significantly different at $p \geq 0.05$ (DMRT).

3.5. Partial Budget Analysis

According to the partial budget analysis, the highest net benefit (215807.76 ETB ha^{-1}) was obtained from the application of 5 t ha^{-1} vermicompost with 100 kg ha^{-1} N rate, followed by net benefit (196835.84 ETB ha^{-1}) obtained from the application of 5 t ha^{-1} vermicompost with 150 kg ha^{-1} N rate. The lowest net benefit (80774.55 ETB ha^{-1}) was recorded from the control treatment (Table 10).

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Table 10 . Partial budget analysis for vermicompost and N-fertilizer effects on wheat yield

VC t ha^{-1}	N- fert. Kg ha^{-1}	Av.GY	Av.SY	Ad. GY (kg ha^{-1})	Ad. SY (kg ha^{-1})	TVC(ETB)	NB (ETB)	MRR (%)
0	0	1836.7	6486.7	1654.68	5838.14	0	80774.55	-
0	50	2683.3	7230	2414.97	6507.06	6007.22	106858.7	434.21
0	100	4176.7	7990	3759.03	7191.07	15596.72	152741.98	478.47
0	150	4663.3	8296.7	4197.01	7467.1	20761.84	165786.31	252.55
2.5	0	2566.7	7160	2310.05	6444.06	14728.41	93783.74	1193.34
2.5	50	3976.7	8393.3	3579.06	7554.04	23006.4	139041.1	546.72
2.5	100	5000	8673.3	4500.04	7806.05	29901.35	169615.38	443.43
2.5	150	5140	8843.3	4626.04	7959.76	32458.94	172482.06	112.09
5	0	4103.3	8250	3693.33	7425.74	31467.49	134830.06	379.77
5	50	4900	8630	4410.44	7767.77	36789.75	157047.28	455.02
5	100	6663.3	10,536.7	5997.57	9492.52	47826.14	215807.76	514.3
5	150	6136.7	11,006.7	5523.58	9907.02	48874.91	196835.84	D
7.5	0	4560	8630	4104.41	7767.77	43902.7	139693.13	1149.24
7.5	50	5616.7	9043.3	5055.54	8139.78	50037.97	172533.08	535.26
7.5	100	6320	10.610	5688.06	9549.95	56794.4	194602.88	326.65
7.5	150	6150	11.086.7	5535.06	9978.13	59004.53	187343.2	D

VC = Vermicompost, N=Nitrogen, Av.GY=average grain yield (t ha^{-1}), Ad. GY=adjusted grain yield (t ha-1), Av.SY = average straw yield (t ha^{-1}), Ad. SY=adjusted straw yield, TVC (ETB)=Total Variable Cost; NB = Net Benefit, ETB = Ethiopian Birr, Market price wheat grain = 40ETB kg-1, Market price of straw= 2.5 ETB kg-1 , Cost of Urea (N-source) fertilizer = 37.5 ETB kg-1,MRR (%)=marginal rate of return.

However, the highest marginal rate of return (1193.34%) was obtained from the sole application of 2.5t/ha vermicompost rate, while the net benefit (93783.74 ETB) was low. According to CIMMYT (1988) suggestion, the minimum acceptable marginal rate of return should be more than 100%. Therefore, the application of 5 t ha^{-1} vermicompost with 100 kg ha^{-1} N resulted in economically the optimum net benefit and total variable cost with acceptable MRR (514.3%) for Wheat grain yield due to the increment of soil nutrients and residual effects in study and similar agro ecology area.

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Table 11. Marginal Analysis of VC and Nitrogen Fertilizer Effects on Wheat Yields

Treatment	VC + N (Rate)	TVC (ETB)	NB (Birr)	MVC (ETB)	MNB (ETB)	MRR (%)
T1	0 + 0	0	80,774.55	–	–	–
T2	0 + 50	6,007.22	106,858.70	6,007.22	26,084.15	434.21
T3	0 + 100	15,596.72	152,741.98	9,589.50	45,883.28	478.47
T4	0 + 150	20,761.84	165,786.31	5,165.12	13,044.33	252.55
T5	2.5 + 0	14,728.41	93,783.74	-6,033.43	-72,002.57	D
T6	2.5 + 50	23,006.40	139,041.10	8,277.99	45,257.36	546.72
T7	2.5 + 100	29,901.35	169,615.38	6,894.95	30,574.28	443.43
T8	2.5 + 150	32,458.94	172,482.06	2,557.59	2,866.68	112.09
T9	5 + 0	31,467.49	134,830.06	-991.45	-37,652.00	D
T10	5 + 50	36,789.75	157,047.28	5,322.26	22,217.22	455.02
T11	5 + 100	47,826.14	215,807.76	11,036.39	58,760.48	514.30
T12	5 + 150	48,874.91	196,835.84	1,048.77	-18,971.92	D
T13	7.5 + 0	43,902.70	139,693.13	-4,972.21	-57,142.71	D
T14	7.5 + 50	50,037.97	172,533.08	6,135.27	32,839.95	535.26
T15	7.5 + 100	56,794.40	194,602.88	6,756.43	22,069.80	326.65
T16	7.5 + 150	59,004.53	187,343.20	2,210.13	-7,259.68	D

VC = Vermicompost, N=Nitrogen, TVC (ETB)=Total Variable Cost; NB = Net Benefit, MVC=Marginal variable cost MNB =Marginal Net Benefit, MRR (%) = marginal rate of return

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4. Summary and Conclusion

The study area has experienced declines in soil fertility and wheat yields due to excessive use of chemical fertilizers. Continuous use of inorganic fertilizers degrades the soil's physical, chemical, and biological properties. In contrast, incorporating vermicompost (VC) improves soil health, increases nutrient availability, and boosts crop productivity. A field experiment was conducted during the 2022 rainy season (June–November) at the Kulumsa Agricultural Research Center in Tiyo woreda to assess the effects of vermicompost (VC) and nitrogen (N) fertilizer on soil characteristics and wheat yield. The experiment used a randomized complete block design with three replications, employing factorial combinations of four urea rates (0, 50, 100, and 150 kg ha^{-1}) and vermicompost rates (0, 2.5, 5, and 7.5 t ha^{-1}).

The findings indicated that vermicompost significantly enhanced soil characteristics, including bulk density, available water holding capacity (AWHC), organic carbon, available phosphorus, exchangeable bases, and cation exchange capacity. At 7.5 t ha^{-1} VC, the lowest bulk density (1.11 g cm^{-3}) and the highest values of AWHC (192.3 mm m^{-1}), organic carbon (3.98%), available phosphorus (15.20 mg kg^{-1}), and cation exchange capacity (26.28 cmol(+) kg^{-1}) were determined. The lowest values were found in the control. The main and interaction effects both had significant effect on total nitrogen and soil pH. The highest total nitrogen (0.311%) resulted from 7.5 t ha^{-1} VC and 150 kg ha^{-1} urea.

The combination of VC and N fertilizer significantly increased grain and biomass yields compared to using them isolated. The highest grain yield (6.66 t ha^{-1}) came from 5 t ha^{-1} VC and 100 kg ha^{-1} urea. This was a significant improvement over the control, in 361.95% yield advantage. Higher rates of both inputs usually led to higher yields, but at the highest levels of both inputs, yields declined. Integrated nutrient management made the soil more fertile and the wheat more productive overall. The study area found that the best way to boost wheat yield was to utilize 5 t ha^{-1} vermicompost and 100 kg ha^{-1} urea combined. However, further, multi-season and multi-location research is necessary to enhance optimal application rates and validate recommendations across various agro-ecological environments.

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